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(54) [Title of the Invention]

Function Generating Device and Temperature-Compensated Oscillation Circuit

(57) [Abstract]

[Purpose] The invention relates to a function generating device and a temperature-compensated oscillation circuit, and has as its purpose to perform desired temperature compensation by applying an inventive idea to a circuit for generating signals proportional to a cubic or other higher-order function and by generating a voltage changeable by those high-order functions to thereby perform desirable temperature compensation.

[Constitution] A function generating device for generating signals $S\alpha$ and Sx proportional to a high-order function $f(x)$ represented by a polynomial: $f(x) = A(x-\alpha)^n \ldots + \beta(x-\alpha) + y = Ax^n + Bx^{n-1} \ldots + Cx + D$. The function generating device comprises a variable generating portion 11 for generating a main variable signal $S\alpha$ proportional to a main variable α and an unknown quantity signal Sx proportional to an unknown quantity x based on a voltage VA proportional to a absolute temperature and a voltage VX to determine the center point of the main variable α. The oscillation circuit comprises a temperature compensating function generating circuit 35 for generating a voltage proportional to a cubic function $f(x)$ and a crystal

oscillation circuit 36 for generating a signal of a desired frequency based on a voltage proportional to the cubic function f(x). The circuit 35 includes a cubic function generating device.

[Claims]

[Claim 1] A function generating device for generating signals proportional to a high-order function represented by a polynomial, comprising a variable generating portion for generating a difference signal between two voltages based on a voltage proportional to an absolute temperature and a reference voltage for determining the center point of a main variable of said polynomial, wherein the center point of said main variable can be varied.

[Claim 2] The function generating device according to Claim 1, comprising at least a gain adjusting circuit for generating a linear signal proportional to a linear function based on a difference signal from said variable generating portion; a first multiplier for generating a second order signal proportional to a second order function based on a difference signal from said variable generating portion; a second multiplier for generating a cubic signal proportional to a cubic function based on a difference signal from said variable generating portion and a second order signal from said first

multiplier; a constant generating portion for generating a 0-th order signal proportional to a constant of said polynomial; a mixer for mixing the linear signal from said gain adjusting circuit, a gain-adjusted version of a second order signal from said first multiplier and a gain-adjusted version of a cubic signal from said second multiplier, and a 0-th order signal from said constant generating portion.

[Claim 3] The function generating device according to Claim 1, comprising at least a linear function generating portion for generating a linear signal proportional to a linear function based on a difference signal from said variable generating portion; a cubic function generating portion for generating a cubic signal proportional to a cubic function based on a difference signal from said variable generating portion; a constant generating portion for generating a 0-th order signal proportional to a constant of said polynomial; and a mixer for mixing a linear signal from said linear function generating portion, a cubic signal from said cubic function generating portion, and a 0-th order signal from said constant generating portion.

[Claim 4] The function generating device according to Claim 1, comprising at least a gain adjusting circuit for generating a linear signal proportional to a linear function based on a difference signal from said variable generating portion; a

first multiplier for generating a second order signal proportional to a second order function based on a difference signal from said variable generating portion; a second multiplier for generating a fourth order signal proportional to a fourth order function based on a second order signal from said first multiplier; a constant generating portion for generating a 0-th order signal proportional to a constant of said polynomial; and a mixer for mixing a linear signal from said gain adjusting circuit, a gain-adjusted version of a second order signal from the first amplifier and a gain-adjusted version of a fourth order signal from said second multiplier, and a 0-th order signal from said constant generating portion.

[Claim 5] A temperature-compensated oscillation circuit, comprising a temperature compensating function generating circuit for generating a voltage proportional to a cubic function; and a crystal oscillation circuit for oscillating a signal of a desired frequency based on a voltage proportional to said cubic function, wherein said temperature compensating function generating circuit includes one of the function generating devices according to Claims 1, 2 and 3.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a function generating device and a temperature-compensated oscillation circuit, more specifically to an improvement of device for generating a temperature compensating function of an oscillation circuit using a crystal resonator. Lately, portable wireless devices are spreading responding to demand for high-speed information transmission, and stable communicating operation is required not only at normal temperature but also under various environmental conditions, including tropical and cold districts. Signals of stable frequencies are necessary for demodulation and modulation processes of wireless equipment.

[0002]

Such frequency signals are generated by the temperature-compensated oscillation circuits using a crystal resonator, and various kinds of methods have been devised to suppress frequency fluctuations owing to temperature changes of the crystal resonator. In the compensation circuit for frequency changes due to temperature changes, because the frequency-temperature change characteristic of the crystal resonator is approximately represented by a cubic function, a correction circuit in proportion to which is required. Incidentally, there is a method of temperature correction approximate to a cubic function, which uses a resistor and a capacitor; however, circuit adjustment is difficult.

[0003]

By making some improvement to a circuit for generating a signal proportional to a cubic or more higher-order function, there has been requirement for a circuit capable of generating a voltage changeable by such a high-order function to perform desired temperature correction and also for its applied version.

[0004]

[Prior Art]

Figs. 9 and 10 are explanatory diagrams for prior art. Fig. 9 is a block diagram of a temperature-compensated crystal oscillation circuit according to prior art. Fig. 10(A) is a temperature-frequency characteristic diagram and Fig. 10(B) is its correction characteristic diagram. For example, a temperature-compensated crystal oscillation circuit as described in United States Patent 4,254,382, for example, includes a temperature compensation circuit 6 and a crystal oscillation circuit 9 as shown in Fig. 9.

[0005]

The temperature compensation circuit 6 includes a temperature sensor 1, a low temperature range correction circuit 2, a medium temperature range correction circuit 3, a high temperature range correction circuit 4, and an I-V conversion circuit 5, and the crystal oscillation circuit 9

includes a resistance and a capacitance C serving as circuit constants, a variable capacitance diode 7, and a crystal resonator 8. The function of the temperature compensation circuit 6 is to correct the temperature-frequency characteristic of the crystal oscillation circuit 9 represented by a cubic function by using a temperature-frequency correction characteristic represented by three straight lines as shown in Fig. 10(B). Note that in Figs. 10(A) and 10(B), the vertical axis indicates frequency fHz and the horizontal axis indicates temperature T℃.

[0006]

More specifically, when an environmental temperature is detected by the temperature sensor 1, a temperature detection signal S1 is sent to a low temperature range correction circuit 2, a medium temperature range correction circuit 3 and a high temperature range correction circuit 4. The signal S1 is compared with a reference voltage V REF by the low temperature range correction circuit 2, and a low temperature range correction signal S2 with a desired temperature dependency is output to an I-V conversion circuit 5. Similarly, in the medium temperature range correction circuit 3, the signal S1 is compared with the reference voltage V REF, and a medium temperature range correction signal S3 is output to the I-V conversion circuit 5, and in the high temperature range

correction circuit 4, the signal S1 is compared with the reference voltage V REF, and a high temperature range correction signal S4 is output to the I-V conversion circuit 5.

[0007]

In the I-V conversion circuit 5, the signals S1 to S4 are added together and this addition sum signal is converted from a current signal into a voltage signal. The voltage as a result of conversion is smoothened by the circuit constants R and C, and a voltage VT with temperature dependency is applied to the variable capacitance diode 7 and the crystal resonator 8. Thus, in the diode 7, its self-capacity is changed by the voltage VT which cancels fluctuations of the environmental temperature, and consequently a signal Sf of a frequency f is output from the crystal resonator 8.

[0008]

[Problem to be solved by the Invention]

Meanwhile, according the prior art, the temperature correction circuits 2 to 4 are allocated respectively to the low, medium and high temperature ranges, and the temperature-frequency characteristic of the crystal oscillation circuit 9 in Fig. 10(A) is approximated by the temperature-frequency correction characteristic shown in Fig. 10(B). Therefore, the frequency changes are corrected individually in each temperature rang and, as a result, the

temperature correction of change points ④ and ⑤ of the three correction characteristic straight-lines in Fig. 10(B) is inferior to the temperature correction of the straight-line segments.

[0009]

In other words, in Fig. 10(B), the correction characteristic straight-line ① is a temperature-frequency correction characteristic of the low temperature range correction circuit 2, the correction characteristic straight-line ② is a temperature-frequency correction characteristic of the medium temperature range correction circuit 3, and the correction characteristic straight-line ③ is a temperature-frequency correction characteristic of the high temperature range correction circuit 4. The change point ④ is a frequency maximum point in the low and medium temperature ranges of the temperature-frequency characteristic represented by a cubic function shown in Fig. 10(A), and the change point ⑤ is similarly a frequency minimum point in the medium and high temperature ranges.

[0010]

Consequently, there is a problem that it is impossible to output a voltage VT in the temperature ranges between the correction characteristic straight-line ① and the correction characteristic straight-line ② and between the correction

characteristic straight-line ② and the correction characteristic straight-line ③ and that it is difficult to perform a smooth temperature compensation throughout the whole span of the low, medium and high temperature ranges. There is a method which uses a network of thermistors, resistors, and capacitors, utilizes a phenomenon in which the capacitance appears to change in relation to temperature, has the capacitance change in a form approximate to a cubic function, and obtains a desired temperature-frequency characteristic. However, because non-linear elements, such as thermistors and capacitors, are used in this case, it is difficult to adjust the elements uniquely. This acts as a drag in achieving temperature compensation with high accuracy and better reliability.

[0011]

The present invention has been made with the problem in the prior art in mind has as its object to provide a function generating device and a temperature-compensated oscillation circuit capable of performing desired temperature compensation by applying an inventive idea to a circuit for generating signals proportional to a cubic or other higher-order function and by generating a voltage changeable by those high-order functions to thereby perform desirable temperature compensation.

[0012]

[Means for solving the Problem]

Figs. 1(A) and 1(B) are principle diagrams of a function generating device and a temperature-compensated oscillation circuit according to the present invention, and Figs. 2 to 6 are their embodiments. A function generating device according to the present invention for generating signals proportional to a high order function f(x) represented by a polynomial: $f(x) = A(x-\alpha)^n \ldots + \beta(x-\alpha) + y = Ax^n + Bx^{n-1} \ldots + Cx + D$ where constants are designated as A, B, C, D, β, γ, a temperature signal as x, and a main variable (hereafter referred to as a reference value) as α. The function generating device includes a variable generating portion 11 for generating a difference signal between voltages VA and VX, the voltage VA being proportional to an absolute temperature and the voltage VX being for determining the above-mentioned reference value α, wherein the voltage VX for determining the reference value α can be varied.

[0013]

A first cubic function generating device, as shown in an embodiment in Fig.2, comprises at least a gain adjusting circuit 21 for generating a linear signal S1 proportional to a linear function Cx based on difference signals $S\alpha$ and Sx from said variable generating portion 11; a first multiplier 22 for

generating a second order signal S2 proportional to a second order function Bx^2 based on difference signals $S\alpha$ and Sx from said variable generating portion 11; a second multiplier 23 for generating a cubic signal S3 proportional to a cubic function Ax^3 based on difference signals $S\alpha$ and Sx from said variable generating portion 11 and a second order signal S2 from said first multiplier 22; a constant generating portion 24 for generating a 0-th order signal proportional to the constant D of the polynomial; a mixer 25 for mixing the linear signal S1 from the gain adjusting circuit 21, a gain-adjusted version of a second order signal S2 from said first multiplier 22 and a gain-adjusted version of a cubic signal S3 from said second multiplier 23, and a 0-th order signal S0 from the constant generating portion 24.

[0014]

A second cubic function generating device, as shown in Fig. 1(A), comprises at least a linear function generating portion 12 for generating a linear signal S1 proportional to a linear function $(x-\alpha)$ based on difference signals $S\alpha$ and Sx from the variable generating portion 11; a cubic function generating portion 13 for generating a cubic signal S3 proportional to a cubic function $A(x-\alpha)^3$ based on difference signals $S\alpha$ and Sx from the variable generating portion 11; a constant generating portion 14 for generating a 0-th order signal S0 proportional

to the constant D of the polynomial; and a mixer 15 for mixing a linear signal S1 from said linear function generating portion 12, a cubic signal S3 from said cubic function generating portion 13, and a 0-th order signal S0 from the constant generating portion 14.

[0015]

A forth order function generating device, as shown in an embodiment in Fig. 7, comprises at least a gain adjusting circuit 30 for generating a linear signal S1 proportional to a linear function $\gamma(x-\alpha)$ based on difference signals ($S\alpha$ and Sx) from the variable generating portion 11; a first multiplier 31 for generating a second order signal S2 proportional to a second order function $\beta(x-\alpha)^2$ based on difference signals $S\alpha$ and Sx from the variable generating portion 11; a second multiplier 32 for generating a fourth order signal S4 proportional to a fourth order function $A(x-\alpha)^4$ based on a second order signal S2 from the first multiplier 31; a constant generating portion 33 for generating a 0-th order signal S0 proportional to a constant δ of the polynomial; and a mixer 34 for mixing a linear signal S1 from the gain adjusting circuit 30, a gain-adjusted version of a second order signal S2 from the first amplifier 31 and a gain-adjusted version of a third order signal S3 from the second multiplier 32, and a 0-th order signal S0 from the constant generating portion 33.

[0016]

A target fourth order function f(x) is provided as $f(x) = Ax^4 + Bx^3 + Cx^2 + Dx + E = A(x-\alpha)^4 + \beta(x-\alpha)^2 + \gamma(x-\alpha) + \delta$. As shown in Fig. 1(B), a temperature-compensated oscillation circuit according to the present invention comprises a temperature compensating function generating circuit 35 for generating a voltage proportional to a cubic function f(x) and a crystal oscillation circuit 36 for oscillating a signal of a desired frequency based on a voltage proportional to the cubic function f(x), wherein the temperature compensating function generating circuit 35 is formed by any of the cubic function generating devices according to the present invention and achieves the above-mentioned object.

[0017]

[Function]

According to a function generating device according to the present invention, in Fig. 1(A), when a voltage VA proportional to an absolute temperature and a voltage for determining a reference value α are supplied to the variable generating portion 11, difference signals S and Sx are generated based on those voltages. Therefore, according to a signal shift amount $(x-\alpha)$ from the variable generating portion 11, the function generating portion can generate signals proportional to a

(n-1)-th or lower order function and also generate signals proportional to a high order function f(x) represented by a polynomial $f(x) = A(x-\alpha)^n ...+ \beta(x-\alpha) + \gamma = Ax^n + Bx^{n-1} ...+ Cx + D$.

[0018]

Referring to Fig. 2, description will be made of the operation of a first cubic function generating device according to the present invention. In Fig. 2, when difference signals Sα and Sx are supplied from the variable generating portion 11 to the gain adjusting circuit 21, the circuit 21, on the basis of those signals, generates a linear signal S1 proportional to a linear function Cx, and this linear signal S1 is output from the gain adjusting circuit 21 to the mixer 25.

[0019]

When the difference signals Sα and Sx are supplied from the variable generating portion 11 to the first amplifier 22, the first amplifier 22, on the basis of those signals, generates a second order signal S2 proportional to a second order function Bx^2, and then a gain-adjusted version of the signal S2 is output to the mixer 25. Furthermore, when the difference signals Sα and Sx from the variable generating portion 11 and a second orde signal S2 from the first amplifier 22 are supplied to the second amplifier 23, on the basis of those signals, a cubic signal S3 proportional to a cubic function Ax^3 is generated, and then a

gain-adjusted version of the signal S3 is output to the mixer 25. A 0-th order signal proportional to the constant D of the polynomial is output from the constant generating portion 24 to the mixer 25. The linear signal S1, a gain-adjusted version of the second order signal S2 and a gain-adjusted version of the cubic signal S3, and the 0-th order signal S0 are mixed by the mixer 25.

[0020]

Consequently, it is possible to generate signals proportional to a cubic function f(x) represented by a polynomial $f(x) = Ax^3 + Bx^2 + Cx + D$ based on temperature-dependent difference signals Sα and Sx from the variable generating portion 11. Thus, it is possible to apply this cubic function generating device to the temperature compensation circuit of the crystal oscillation circuit.

[0021]

Description will now be made of the operation of a second cubic function generating device according to the present invention. In Fig. 1(A), when difference signals Sα and Sx from the variable generating portion 11 are supplied to the linear function generating portion 12, this generating portion 12, on the basis of those signals, generates a linear signal S1 proportional to a linear function (x−α), and this linear signal S1 is output from the linear function generating portion 12 to

the signal mixer 15.

[0022]

Further, when difference signals $S\alpha$ and Sx from the variable generating portion 11 are supplied to the cubic function generating portion 13, this generating portion 13, on the basis of those signals, generates a cubic signal S3 proportional to a cubic function $A(x-\alpha)^3$, and this cubic signal S3 is output from the cubic function generating portion 13 to the signal mixer 15. A 0-th order signal S0 proportional to the D in the polynomial output from the constant generating portion 14 to the signal mixer 15. The linear signal S1, the cubic signal S3, and the 0-th order signal S0 are mixed by the signal mixer 15.

[0023]

As a result, on the basis of difference signals $S\alpha$ and Sx proportional to a temperature from the variable generating portion 11, signals can be generated which are proportional to a cubic function f(x) represented by a polynomial $f(x) = A(x-\alpha)^3 \ldots + \beta(x-\alpha) + \gamma = Ax^3 + Bx^2 \ldots + Cx + D$. In the second cubic function generating device, because it becomes unnecessary to provide the first multiplier 22 that generates a second order signal S2 required for the first cubic function generating device, it is possible to reduce the size of the circuit.

[0024]

Thus, as with the first cubic function generating device, it is possible to apply the second cubic function generating device to the temperature compensation circuit of the crystal oscillation circuit. Referring to Fig. 7, description will next be made of a fourth order function generating device of the present invention. In Fig. 7, when difference signals Sα and Sx from the variable generating portion 11 are supplied to a gain adjusting circuit 30, this gain adjusting circuit 30, on the basis of those signals, generates a linear signal S1 proportional to a linear function Dx, and this signal S1 is output from the gain adjusting circuit 30 to the mixer 34.

[0025]

In addition, when difference signals Sα and Sx are supplied from the variable generating portion 11 to a first multiplier 31, this first multiplier 32, on the basis of those signals, generates a second order signal S2 proportional to a second order function Cx^2 and this signal S2 is output on one side to a second multiplier 32 and, on the other side, this signal S2, after its gain has been adjusted, is output to the mixer 34. When a second order signal S2 is supplied from the first multiplier 31 to the second multiplier 32, this multiplier 32, on the basis of this signal S2, generates a fourth order signal S4 proportional to a fourth order function Ax^4, and this signal

S4 is adjusted in gain and output to the mixer 34. A 0-th order signal S0 proportional to the constant E of the polynomial is output from a constant generating portion 33 to the mixer 34.

[0026]

The linear signal S1, the second order signal S2, the fourth order signal S4, and the 0-th order signal S0 are mixed by the signal mixer 34. Consequently, on the basis of difference signals Sα and Sx from the variable generating portion 11, it is possible to generate signals proportional to a fourth order function f(x) represented by a polynomial $f(x) = Ax^4 + Bx^3 + Cx^2 + Dx + E$.

[0027]

Thus, without providing a cubic function generating portion for generating a cubic signal S3, only by connecting in cascade two second order function generators each generating a second order signal S2, it is possible to form a fourth order function generating device in a simple fashion. Referring to Figs. 1(A) and 1(B), description will now be made of the operation of an oscillation circuit added with temperature compensation according to the present invention. In Fig. 1(B), when the temperature compensating function generating circuit 35, including a second cubic function generating device of this invention, generates a voltage proportional to a cubic function f(x) with temperature dependency, on the basis of this voltage,

the voltage-controlled crystal oscillation circuit 36 oscillates a signal of a desired frequency.

[0028]

Therefore, it is possible for the temperature compensating function generating circuit 35 to compensate smoothly and with high accuracy the frequency changes under a temperature environment, in which the crystal oscillation circuit 36 is located. Therefore, it is possible to supply a stable frequency signal to the demodulation and modulation circuits in wireless equipment, for example.

[0029]

[Embodiments]

Preferred embodiments of the present invention will be described with reference to the accompanying drawings. Figs. 2 to 8 are explanatory diagrams of a function generating device and a temperature-compensated oscillation circuit according to individual embodiments of the present invention.

(1) Description of a First Embodiment

Fig. 2 is a block diagram of a cubic function generating device according to a first embodiment of the present invention, and Fig. 3 is a circuit diagram the variable generating portion of each embodiment.

[0030]

For example, a function generating device for generating

a signal proportional to a cubic function f(x), as shown in Fig. 1(A), comprises a variable generating portion 11, gain adjusting circuits 21, 22A, 23A, multipliers 22, 23, a constant generating portion 24, and a mixer 25. The cubic function f(x) is represented by a polynomial $f(x) = A(x-\alpha)^3 + \beta(x-\alpha) + \gamma = Ax^3 + Bx^2 + Cx + D$ where constants are designated as A, B, C, D, β, γ, a temperature signal as x, and a reference value as α.

[0031]

Specifically, the variable generating portion 11 is a circuit for generating difference signals $S\alpha$ and Sx based on a voltage VA proportional to an absolute temperature and a voltage VX to determine a reference value α. As shown in Fig. 3, the variable generating portion 11 includes an input circuit 101, a voltage divider circuit 102, a first difference output circuit 103, a second difference output circuit 104, current mirror circuits 105, 106. The input circuit 101 includes six resistors R1 to R6, three pnp bipolar transistors T1 to T3, and two npn bipolar transistors T4, T5, and generates a voltage VA proportional to the absolute temperature based on a band-gap voltage VB proportional to an environmental temperature, and outputs the voltage VA to the difference output circuits 103 and 104. Meanwhile, for a method of connection of the resistors R1 to R6 and the transistors T1 to T5, refer to Fig. 3.

[0032]

The voltage divider circuit 102 consists of the resistors R7, R8, and outputs the voltage VX for determining a reference value α obtained by dividing the band-gap voltage VB between the resistors to the difference output circuit 103. Meanwhile, the voltage VX may be made variable by using a variable resistor for the resistor R8. The first difference output circuit 103 includes the resistors R9, R10, R18, an Op-Amp OP1 and a bipolar transistor Q0, and receives a voltage VA proportional to an absolute temperature and a voltage VX for determining the center point of the main variable and outputs a current Ix proportional to an unknown to the current mirror circuit 105.

[0033]

The second difference output circuit 104 includes a resistance R11, a npn bipolar transistor T6, and an Op-Amp OP2, and receives a voltage VA proportional to an absolute temperature and a reference current VR output from one side of the resistor R11 and outputs a voltage Vα proportional to the reference value α to the current mirror circuit 106. The current mirror circuit 105 includes two resistors R12, R13, and two pnp bipolar transistors T7, T8. This circuit 105 generates a difference signal Sx based on a current Ix. Similarly, the current mirror circuit 106 includes two resistors R14, R15 and two pnp bipolar transistors T9, T10. This circuit 106 generates

a difference signal Sα based on a current Iα.

[0034]

In Fig. 2, the gain adjusting circuit 21 generates a linear signal S1 proportional to a linear function Cx based on difference signals Sα and Sx from the variable generating portion 11, and outputs the signal S1 to the mixer 25. The first multiplier 22 generates a second order signal S2 proportional to a second order function Bx^2 based on difference signals Sα and Sx from the variable generating portion 11, and outputs this signal S1 to the gain adjusting circuit 22A.

[0035]

The second multiplier 23 generates a cubic signal S3 proportional to a cubic function Ax^3 based on difference signals Sα and Sx from the variable generating portion 11 and a second order signal S2 from the first multiplier 22, and outputs this signal S3 to the gain adjusting circuit 22A. The constant generating portion 24 is formed by a reference voltage source, and generates a 0-th order signal proportional to the constant D of the polynomial and outputs this signal S0 to the mixer 23.

[0036]

The gain adjusting circuit 22A adjusts the gain of the second order signal S2 and then outputs this second order signal S22 to the mixer 25. Similarly, the gain adjusting circuit 23A adjusts the gain of the third order signal S3 and then outputs

this third order signal S33 to the mixer 25. The mixer 25 mixes the first order signal S1 from the gain adjusting circuit 21, the linear signal S22 from the gain adjusting circuit 22A, the cubic signal S33 from the gain adjusting circuit 23A and the 0-th order signal S0 from the constant generating portion 24, and outputs a signal f(x) proportional to a cubic function.

[0037]

Under the configuration described above, for example, when a voltage VA proportional to an absolute temperature and a voltage VX for determining a reference value α are supplied to the variable generating portion 11 in Fig. 3, on the basis of these voltages, difference signals $S\alpha$ and Sx are generated. Thus, a cubic function generating device according to a first embodiment of the present invention, as shown in the embodiment of Fig. 2, the cubic function generating device includes the variable generating portion 11, the gain adjusting circuit 21, the first and second multipliers 22, 23, the constant generating portion 24, and the mixer 25. Because the variable generating portion 11 generates the difference signals $S\alpha$ and Sx based on the voltage VA proportional to the absolute temperature and the voltage VX to determine a reference value α, according to the temperature-dependent difference signals $S\alpha$ and Sx from the variable generating portion 11, it is possible to generate signals proportional to a cubic function f(x) represented by

a polynomial $f(x) = Ax^3 + Bx^2 + Cx + D$.

[0038]

Furthermore, by making the voltage VX to determine the reference value α variable by resistor R8 in the variable generating portion 11, it is possible to shift and supply the difference signal $S\alpha$ to the function generating circuit 23. Therefore, it is possible to apply the cubic function generating device to the temperature compensation circuit of the crystal oscillation circuit.

[0039]

(2) Description of a Second Embodiment

Fig. 4 is a block diagram of a cubic function generating device according to a second embodiment of the present invention, and Fig. 5 shows a variable generating portion of the device and a peripheral circuit of the variable generator. Fig. 6 shows a cubic function generator and its peripheral circuit in the second embodiment. In the second embodiment, attempt was made to realize a smaller circuit than in the first embodiment.

[0040]

As shown in Fig. 4, the second cubic function generating circuit of the present invention includes a variable generating portion 100, gain adjusting circuits 26, 27A, a cubic function generator 27, a constant generating portion 28, and a mixer 29. The variable generating portion 100 is formed by adding a

starter circuit 107, an amplifier 108, and a linear function generating circuit 12, respectively shown in Fig. 5, to the variable generating portion 11 in Fig. 3. In Fig. 5, the starter circuit 107 includes two resistors R16, R17, five npn bipolar transistors T11 to T15, and a capacitor C. Simultaneously with turning ON of power supply, a band-gap voltage VB proportional to the environmental temperature is supplied to the voltage divider circuit 102 described above. Meanwhile, for a method of connecting the resistors R16, R17 and the transistors T11 to T15, and the capacitor C, refer to Fig. 5.

[0041]

The amplifier 108 amplifies the output voltage of the Op-Amp OP1, and outputs a current Ix proportional to an amplified reference signal x to the current mirror circuit 105. The linear function generating circuit 12 generates a signal (hereafter referred to as a linear signal) S1 proportional to a linear function ($x-\alpha$) in which a difference signal Sx from the current mirror circuit 105 and a difference signal Sα from the current mirror circuit 106 are current-mirrored, and outputs this signal S1 to a gain adjusting circuit 26.

[0042]

In Fig. 6, the gain adjusting circuit 26 includes an Op-Amp OP4 and two resistors R716, R717 and, after adjusting the gain of the linear function signal S1, outputs the signal S1 to a

mixer 29. The cubic function generator 27 is an example of the cubic function generating portion 13 in Fig. 1, for this function generator, a function generator is used, for which the present applicant of the present invention previously filed a patent application (Japan Patent Application No. 6-139020). This cubic function generator 27 includes 15 resistors R71 to R715, 22 npn bipolar transistors T71 to T720, T725, T726, four pnp bipolar transistors T721 to T724, and four current-voltage conversion diodes D1 to D4, and generates a cubic signal S3 proportional to a cubic function $A(x-\alpha)^3$ based on the difference signals $S\alpha$ and Sx from the variable generating portion 100, and outputs this signal S3 to the gain adjusting circuit 27A. Meanwhile, for a method of connecting the resistors R71 to R715 and the transistors T71 to T726, and the diodes D1 to D4, refer to Fig. 6.

[0043]

In this generator 27, signals of a second order function component in $A(x-\alpha)^3$ are generated by two differential amplifier circuits constituted by the four transistors T79 to T712 of lower branches, and signals of the cubic function component in $A(x-\alpha)^3$ are generated by four differential amplifier circuits constituted by the eight transistors T713 to T720 of upper branches. The gain adjusting circuit 27A includes an Op-Amp OP5, a reference voltage source E1 and two resistors R718, R719

and, after adjusting the gain of the cubic function signal S3, outputs the signal S3 to the mixer 29. The constant generating portion 28 is an example of the constant generating portion 14 of Fig. 1, includes a reference voltage variable source E2 and the resistor R719, and generates a 0-th order signal S0 proportional to the constant D of the polynomial.

[0044]

The mixer 29 is an example of the signal mixer 15 in Fig. 1, and it mixes two signals S1 and S3 whose gains have been adjusted and the 0-th order signal S0 from the constant generating portion 28, and outputs a signal proportional to a cubic function f(x) represented by a polynomial $f(x) = Ax^3 + Bx^2 + Cx + D$. Description will next be made of the operation of a cubic function generating device according to the second embodiment of the present invention. For example, in Fig. 5, in the variable generating portion 100, a band-gap voltage VB is generated in the variable generating portion 100 by a power ON operation of the starter circuit 107, and difference signals $S\alpha$ and Sx are generated by two current mirror circuits 105, 106, and when those signals are supplied to the linear function generating portion 12 and the linear function generating portion 12 generates a linear signal S1 proportional to a linear function $(x-\alpha)$ based on the difference signals, this signal S1 is output from the linear function generating portion 12 to the

gain adjusting circuit 26. δ

[0045]

When the difference signals $S\alpha$ and Sx from the variable generating portion 100 are supplied to the cubic function generator 27, the generator 27 generates a cubic signal S3 proportional to a cubic function $A(x-\alpha)^3$ based on the difference signals, and this signal S3 is output from the cubic function generator 27 to the gain adjusting circuit 27A. A 0-th order signal S0 proportional to δ related to a constant D of the polynomial is output from the constant generating portion 28 to the mixer 29. The relation between the constant D and δ is such that $-3A\alpha^3 - \alpha\beta + \gamma = D$ when a polynomial $f(x) = Ax^3 + Bx^2 + Cx + D = A(x-\alpha)^3 + \beta(x-\alpha) + \gamma$.

[0046]

Two signals S1, S3, the gains of which have been adjusted, and a 0-th order signal S0 from the constant generating portion 28 are mixed by the mixer 29, and a signal proportional to a cubic function f(x) represented by a polynomial $f(x) = Ax^3 + Bx^2 + Cx + D = A(x-\alpha)^3 + \beta(x-\alpha) + \gamma$ is output

Where $\alpha = B/A$, $\beta = C-3A\alpha^2$, $= D + 3A\alpha^3 + \alpha\beta$.

[0047]

As has been described, in Fig. 4, a cubic function generating device according to a second embodiment of the present invention includes a variable generating portion 100,

gain adjusting circuits 27, 27A, a cubic function generator 27, a constant generating portion 28, and a mixer 29; therefore, on the basis of temperature-dependant difference signals Sα and Sx from the variable generating portion 100, it is possible to generate a signal proportional to a cubic function f(x) represented by a polynomial $f(x) = A(x-\alpha)^3 + \beta(x-\alpha) + \gamma = Ax^3 + Bx^2 + Cx + D$.

[0048]

According to the second embodiment, the multiplier 22 for generating a second order signal S2 required in the first embodiment is made unnecessary, making it possible to reduce the size of the circuit. More specifically, in the first embodiment, it was necessary to provide the variable generating portion 11, the mixer 25 for mixing four signals S1, S22, S33, and S0, the three gain adjusting circuits 21, 22A, and 23A, and the two multipliers 22, 23. On the other hand, in the second embodiment, the multiplier 22 and the gain adjusting circuit 22 for the multiplier 22 are made unnecessary. Furthermore, in the first embodiment, the mixer 25 requires four inputs; however, in the second embodiment, the mixer 29 three inputs, one less than in the first embodiment. Furthermore, the amplifier 107 and the linear function generating circuit 12 are added in the variable generating portion 100, but those circuits are required also in the first embodiment. Thus, overall, it

is possible to reduce the circuit size and decrease the adjusting parts and error-inducing factors.

[0049]

Thus, as in the first embodiment, it is possible to apply the cubic function generating device according to the second embodiment to the temperature compensation circuit of the crystal oscillation circuit and provide a compensation signal generating circuit at lower cost and with higher accuracy than in the first embodiment.

(3) Description of a Third Embodiment

Fig. 7 is a block diagram of a fourth order function generating device according to a third embodiment of the present invention. In the third embodiment, unlike in the first and second embodiments, a circuit is formed to generate a signal proportional to a fourth order function $f(x) = Ax^2 + Bx^3 + Cx^2 + Dx + E = A(x-\alpha)^4 + \beta(x-\alpha)^2 + \gamma(x-\alpha) + \delta$.

[0050]

As shown in Fig. 7, the fourth order function generating device according to the present invention includes a variable generating portion 11, a gain adjusting circuit 30, multipliers 31, 32, gain adjusting circuits 31A, 32A, a constant generating portion 33, and a mixer 34. The gain adjusting circuit 30 generates a linear signal S1 proportional to a linear function $\gamma(x-\alpha)$ based on difference signals $S\alpha$ and Sx from the variable

generating portion 11, and outputs this signal S1 to the mixer 34. The multiplier 31 generates a second order signal S2 proportional to a second order function $\beta(x-\alpha)^2$ based on difference signals $S\alpha$ and Sx from the variable generating portion 11, and outputs this signal S2 to the gain adjusting circuit 31A and the multiplier 32, respectively.

[0051]

The multiplier 32 generates a fourth order signal S4 proportional to a fourth order function $A(x-\alpha)^4$ based on a second order signal S2 from the multiplier 31, and outputs this signal S4 to the gain adjusting circuit 32A. The gain adjusting circuit 32A outputs a signal S22 as a gain-adjusted version of the second order signal S2 to the mixer 34. The gain adjusting circuit 32A outputs a signal S44 as a gain-adjusted version of the fourth order signal S4 to the mixer 34.

[0052]

The constant generating portion 33 generates a 0-th order signal S0 proportional to a constant δ of the second polynomial, and outputs this signal S0 to the mixer 34. The mixer 34 mixes the linear signal S1 from the gain adjusting circuit 30, the second order signal S22 from the gain adjusting circuit 31A, the fourth order signal S44 from the gain adjusting circuit 32A, and the 0-th order signal S0 from the constant generating portion 33, and outputs a signal proportional to a fourth

function $f(x) = Ax^4 + Bx^3 + Cx^2 + Dx + E$.

[0053]

Description will be made of the operation of a fourth order function generating device according to a third embodiment of the present invention. In Fig. 7, when difference signals $S\alpha$ and Sx from the variable generating portion 11 are supplied to the gain adjusting circuit 30, the adjusting circuit 30, on the basis of those signals, generates a linear signal S1 proportional to a linear function Cx, and outputs this signal S1 to the mixer 34.

[0054]

Also, when difference signals $S\alpha$ and Sx from the variable generating portion 11 are supplied to the multiplier 31, the multiplier 31, on the basis of those signals, generates a second order signal S2 proportional to a second order function Cx^2, and outputs this signal S2, on one side, to the multiplier 32. On the other side, this signal is adjusted in gain and becomes a signal S22 which is output to the mixer 34. When a second order signal S2 is supplied to the multiplier 32, the multiplier 32, on the basis of the signal S2, generates a fourth order signal S4 proportional to a fourth order function Ax^4, and after the signal S4 is subjected to gain adjustment, a signal S44 is output to the mixer 34. A 0-th order signal S0 proportional to the constant E of the polynomial is output from the constant

generating portion 33 to the mixer 34.

[0055]

The linear signal S1, the second order signal S22, the fourth order signal S44, and a 0-th order signal S0 are mixed by the signal mixer 34, and a signal proportional to a fourth order function $f(x) = Ax^4 + Bx^3 + Cx^2 + Dx + E$ is output. The relation among A, B, C, D, E, α, β, γ, and δ is: $\beta = -4A\alpha$, $C = 6A\alpha^2 + \beta$, $D = -4A\alpha - 2\alpha\beta + \gamma$, $E = A\alpha^4 + \alpha^2 \beta - \alpha\gamma + \delta$.

[0056]

As has been described, in a fourth order function generating device according to the third embodiment of the present invention, as shown in Fig. 7, the variable generating portion 11 is connected with the gain adjusting circuit 30, the first and second multipliers 31, 32, the constant generating portion 33, and the mixer 34. Therefore, it is possible to generate a signal proportional to a fourth order function f(x) represented by a polynomial $f(x) = Ax^4 + Bx^3 + Cx^2 + Dx + E$ based on temperature-dependent difference signals $S\alpha$ and Sx from the variable generating portion 11.

[0057]

Thus, without providing a third order function generating portion for generating a third order signal S3, only by connecting in cascade two second-order-function generating multipliers 31, 32 each generating a second order signal S2,

it is possible to constitute a fourth order function generating device in a simple fashion. Meanwhile, with regard to a fifth or more higher order function generating device, they can generate various correction signals with higher accuracy indeed, but they will require a circuit on a larger scale, and therefore in the method of the present invention which uses analog multipliers, such high order function generating devices are not so practical because errors such as offset occur.

[0058]

However, obviously, by using the variable generating portion 11 of the present invention, a function generating circuit for generating a function of the second highest order term can be made unnecessary, which offers an effect of reducing the size of the circuit.

(4) Description of a Fourth Embodiment

Fig. 8 is a block diagram of a temperature-compensated crystal oscillation circuit according to a fourth embodiment of the present invention. In the fourth embodiment, the cubic function generating device in the first and second embodiments is connected to the crystal oscillation circuit to constitute a temperature compensation circuit.

[0059]

As shown in Fig. 8, the temperature-compensated oscillation circuit of the present invention includes a

temperature compensating function generating circuit 35 and a voltage-controlled crystal oscillation circuit 36. The temperature compensating function generating circuit 35 is one which generates a voltage VT proportional to a cubic function f(x). For the function generating circuit 35, a cubic function generating device according to the second embodiment, for example, is used. Or, a cubic function generating device according to the first embodiment may be used.

[0060]

The crystal oscillation circuit 36 oscillates a signal of a desired frequency based on a voltage VT corresponding to a cubic function f(x). The crystal oscillation circuit 36 includes a resistor R, a capacitor C, a variable capacitance diode 7, and a crystal resonator 8. The capacitor C is used to remove noise, and the resistor R is connected to make a capacitance component from the variable capacitance diode side invisible, and the voltage VT is applied through the resistor R to the variable capacitance diode 7 and the crystal resonator 8.

[0061]

The variable capacitance diode 7 varies the self-capacitance of the crystal resonator 8 based on the voltage VT. The crystal resonator 8 outputs a designed frequency signal Sf based on the voltage VT which is variable with changes of

an environmental temperature. With reference to Fig. 7, description will be made of the operation of the temperature-compensated oscillation circuit of the present invention. In Fig. 7, when a voltage VT proportional to a temperature-dependant cubic function f(x) is generated by the temperature compensating function generating circuit 35 which includes a cubic function generating device according to the second embodiment of the present invention, on the basis of the voltage VT, the crystal oscillation circuit 36 oscillates a signal Sf of desired frequency stable against temperature, based on the voltage VT.

[0062]

As shown in Fig. 8, the temperature-compensated oscillation circuit according to a fourth embodiment of the present invention comprises a temperature compensating function generating circuit 35 and a crystal oscillation circuit 36, and this function generating circuit 35 includes any of the cubic function generating devices of the present invention. Therefore, by this temperature compensating function generating circuit 35, it is possible to smoothly correct frequency changes under a temperature environment in which the crystal oscillation circuit 36 is located, according to a voltage VT proportional to a cubic function $f(x) = Ax^3 + Bx^2 + Cx + D$. More specifically, it is possible to continuously

output a voltage VT in temperature ranges between the correction characteristic straight-line ① and the correction characteristic straight-line ② and between the correction characteristic straight-line ② and the correction characteristic straight-line ③ as in prior art and it is possible to obtain a correction characteristic curve with continuous points of frequency changes.

[0063]

Consequently, it is possible to obtain a smooth temperature-frequency correction characteristic for a whole span of the low, medium and high temperature ranges, and perform temperature compensation with high accuracy and reliability. Thus, it is possible to supply. And, it is possible to supply the demodulating circuit and the modulating circuit of wireless equipment, for example, with stable frequency signals. Furthermore, a temperature-compensated crystal oscillation circuit of small size is provided at low cost.

[0064]

[Effect of the Invention]

As has been described, according to a function generating device of the present invention, because there is provided a variable generating portion for generating a difference signal proportional to a principal variable based on a voltage proportional to an absolute temperature and a voltage to

determine the center point of the principal variable, it is possible to supply a temperature-dependent difference signal from the variable generating portion to the function generating portion for generating a signal proportional to the highest n-th order function.

[0065]

Moreover, according to the function generating device of the present invention, because the voltage to determine the center point of the principal variable is made changeable in the variable generating portion, it is possible to shift and supply an input signal to the function generating portion. Therefore, it is possible for the function generating portion to generate a signal proportional to an (n-1)-th order function or a more lower order function according to a signal shift amount from the variable generating portion.

[0066]

According to the first cubic function generating device of the present invention, because the variable generating portion includes the gain adjusting circuits, the two multipliers, the constant generating portion, and the mixer, it is possible to generate a signal proportional to a cubic function f(x) represented by a polynomial $f(x) = Ax^3 + Bx^2 + Cx + D$ on the basis of temperature-dependent difference signals from the variable generating portion. According to the second

cubic function generating device of the present invention, because the variable generating portion includes the linear function generating portion, the cubic function generating portion, the constant generating portion, and the signal mixer, it is possible to generate a signal proportional to a cubic function F(x) represented by a polynomial $f(x) = A(x-\alpha)^3 + \beta(x-\alpha) + \gamma = Ax^3 + Bx^2 + Cx + D$ on the basis of temperature-dependent difference signals from the variable generating portion. Furthermore, it is possible to make the circuit size smaller than in the first cubic function generating device.

[0067]

According to the fourth order function generating device of the present invention, because the variable generating portion includes the gain adjusting circuits, the two multipliers, the constant generating portion, and the mixer, without providing a cubic function generating portion for generating a cubic signal, only by connecting in cascade two second order function generating portions for generating a second order signal, it is possible to generate a signal proportional to a fourth order function easily based on difference signals from the variable generating portion, and it is also possible to configure this device in a simple fashion.

[0068]

According to the present invention, a temperature-compensated oscillation circuit includes a temperature compensating function generating circuit and a crystal oscillation circuit, and because this function generating circuit includes either the first or second function generating device, it is possible to compensate frequency changes under a temperature environment, in which the crystal oscillation circuit is located, smoothly and with high accuracy by the temperature compensating function generating circuit. Consequently, it is possible to supply stable frequency signals to the demodulating circuit and the modulating circuit in wireless equipment or the like. Thus, the present invention will make a great contribution to downsizing and cost reduction of the temperature compensated crystal oscillation circuits.

[Brief Description of the Drawings]

Fig. 1 is a principle diagram of a function generating device and a temperature-compensated oscillation circuit according to the present invention;

Fig. 2 is a block diagram of a cubic function generating device according to a first embodiment of the present invention;

Fig. 3 is a circuit diagram of a variable generating portion of each embodiment of the present invention;

Fig. 4 is a block diagram of a cubic function generating device of a second embodiment of the present invention;

Fig. 5 is a diagram showing a variable generating portion and its peripheral circuit according to the second embodiment of the present invention;

Fig. 6 is a diagram showing a cubic function generator and its peripheral circuit according to the second embodiment of the present invention;

Fig. 7 is a block diagram of a fourth order function generating device according to a third embodiment of the present invention;

Fig. 8 is a block diagram of a temperature-compensated crystal oscillation circuit according to a fourth embodiment of the present invention;

Fig. 9 is a block diagram of a temperature-compensated crystal oscillation circuit according to prior art; and

Fig. 10 is a temperature compensation characteristic diagram for explaining the problem in the prior art.

[Description of Codes]

11, 100 ... Variable generating portion

12 ... Linear function generating portion

13 ... Cubic function generating portion

14, 24, 28, 33 ... Constant generating portions

15 ... Signal mixer

21, 22A, 23A, 26, 27A, 30, 31A, 32A ... Gain adjusting circuits

22, 23, 31, 32 ... Multipliers

25, 29, 34 ... Mixers

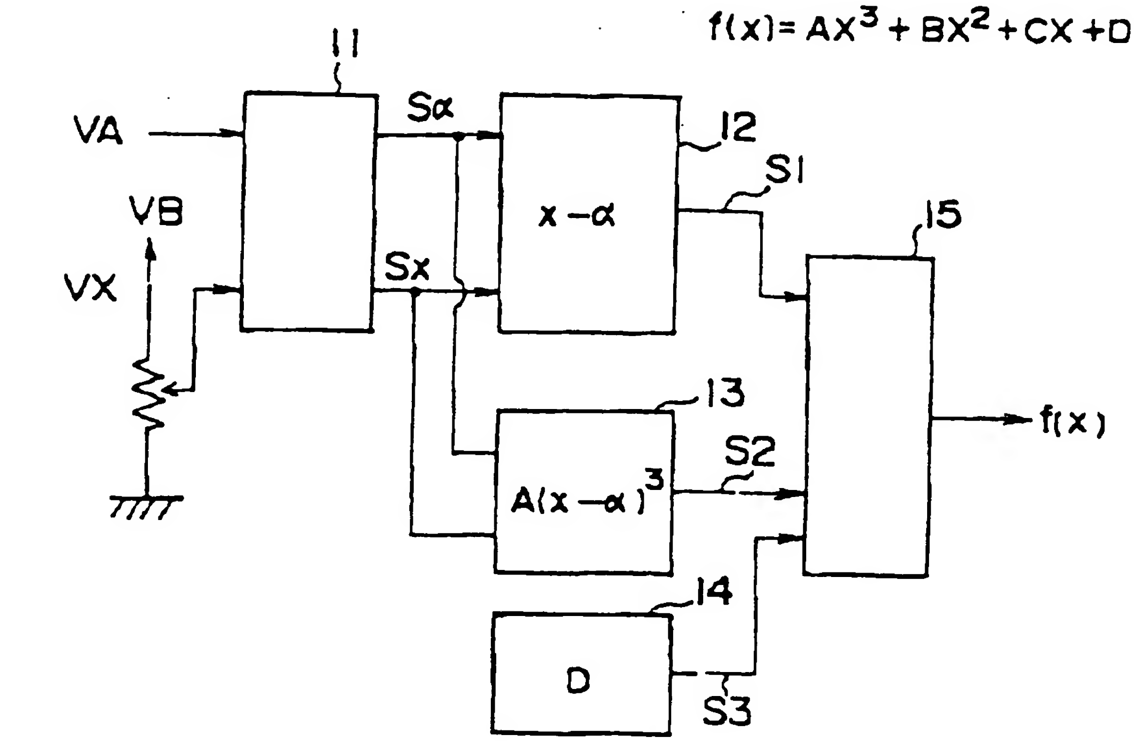
27 ... Cubic function generating portion

35 ... Temperature-compensating function generating circuit

36 ... Temperature-controlled crystal oscillation circuit

FIG. 1

(a)



11 ; VARIABLE GENERATING CIRCUIT

12 ; LINEAR FUNCTION GENERATING PORTION

13 ; CUBIC FUNCTION GENERATING PORTION

14 ; CONSTANT GENERATING CIRCUIT

15 ; SIGNAL MIXER

(b)

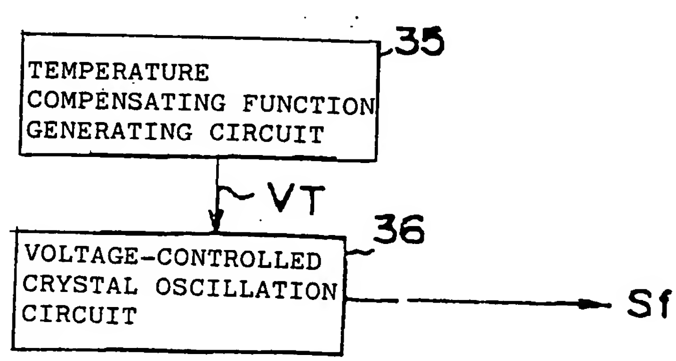
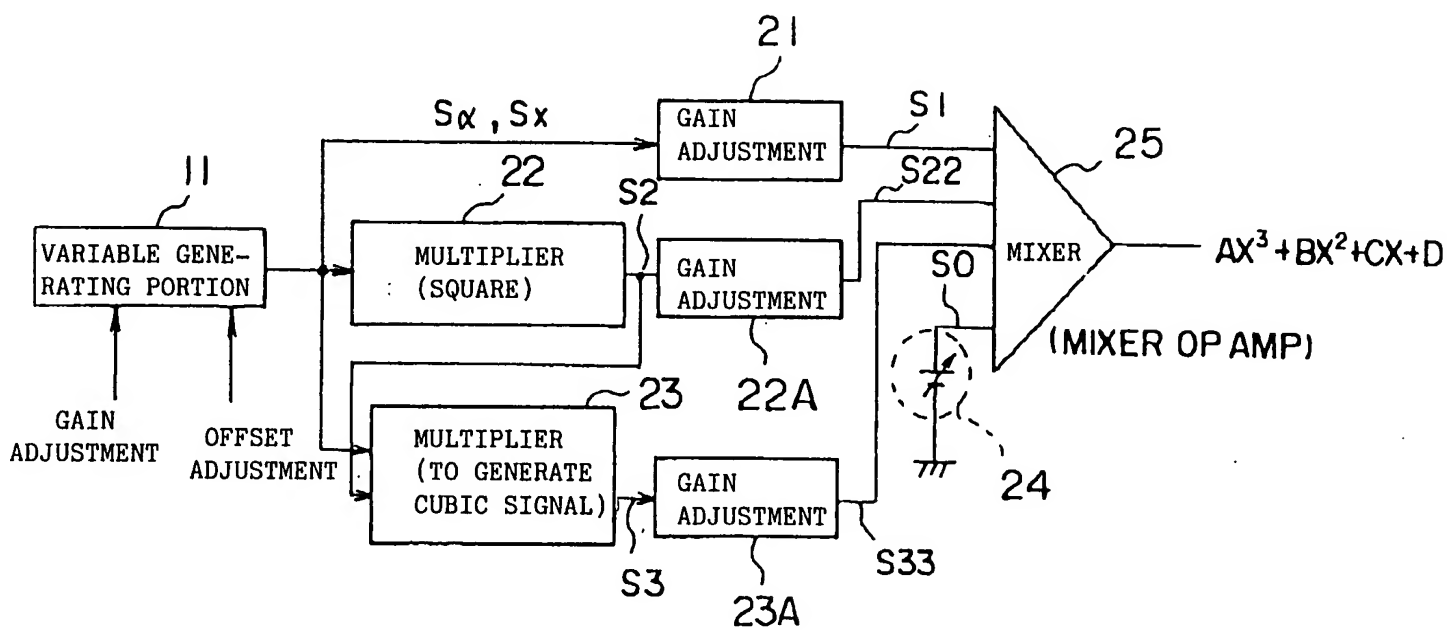


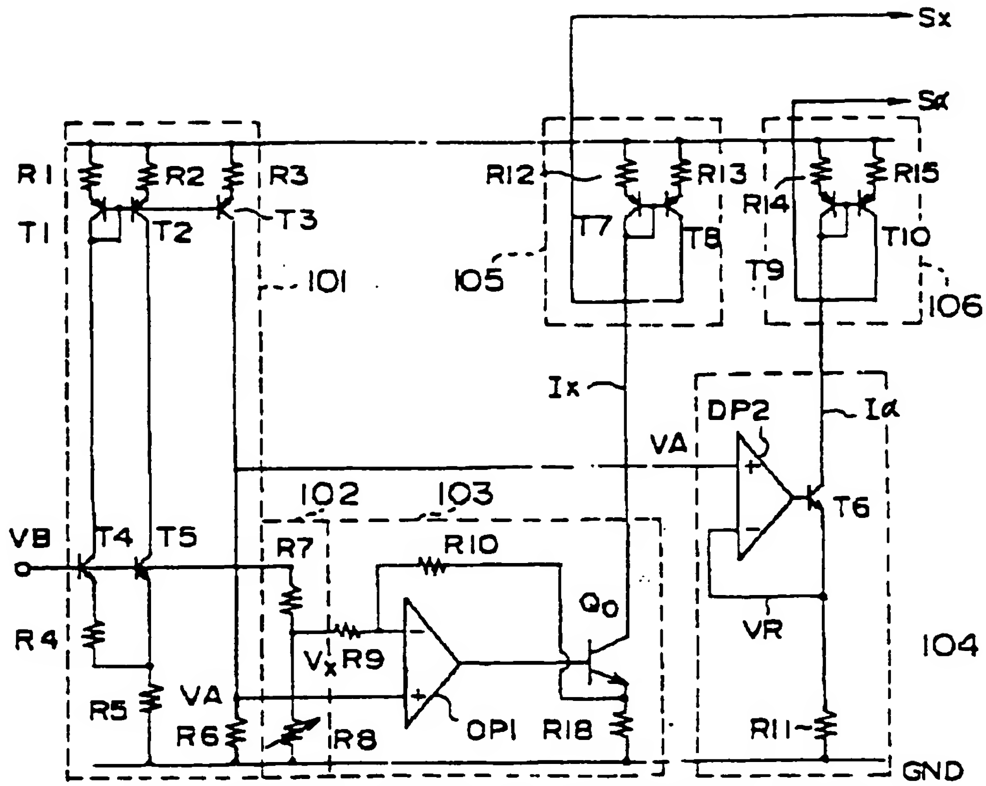
FIG. 2



24; CONSTANT GENERATING PORTION

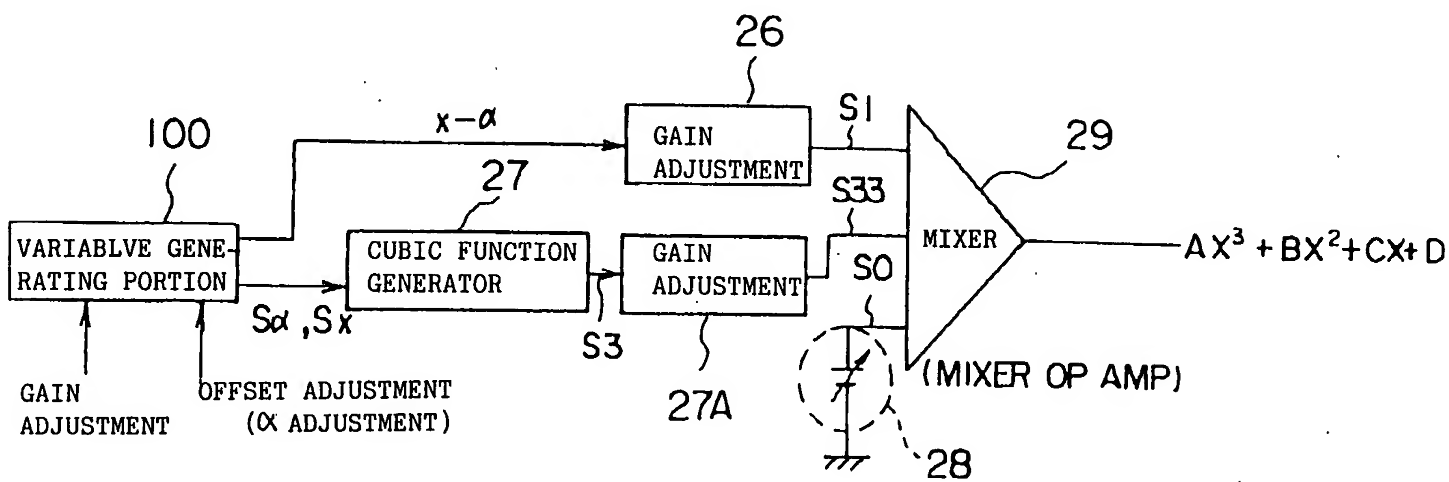
SO; 0-th ORDER SIGNAL

FIG. 3



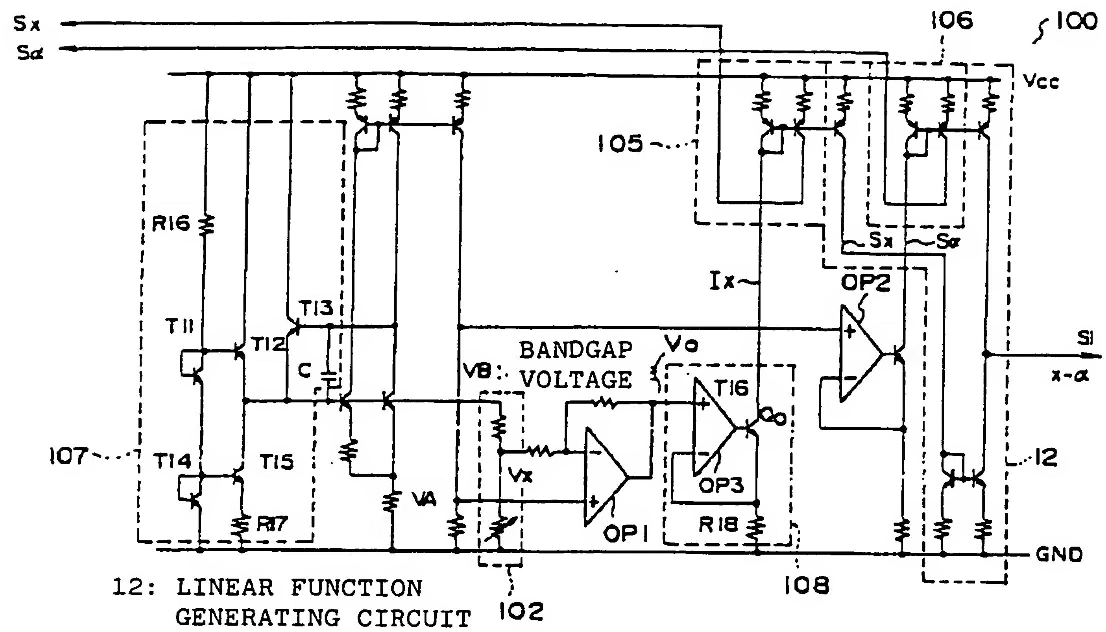
VA: ABSOLUTE TEMPERATURE PROPORTIONAL VOLTAGE
V : VOLTAGE (α) TO DETERMINA CENTER POINT OF MAIN VARIABLE (VT)
VB: BAND-GAP VOLTAGE
101 : INPUT CIRCUIT
102 ; VOLTAGE DIVIDER CIRCUIT
103 ; MAIN VARIABLE OUTPUT CIRCUIT
104 : UNKNOWN NUMBER OUTPUT CIRCUIT
105,106; CURRENT MIRROR CIRCUITS

FIG. 4



100
VARIABLVE GENE-RATING PORTION
GAIN ADJUSTMENT
OFFSET ADJUSTMENT (α ADJUSTMENT)
Sα ,Sx
x−α
27
CUBIC FUNCTION GENERATOR
S3
26
GAIN ADJUSTMENT
27A
GAIN ADJUSTMENT
S1
S33
S0
28
29
MIXER
(MIXER OP AMP)
AX³ + BX²+CX+D

FIG. 5



12: LINEAR FUNCTION GENERATING CIRCUIT
107: STARTER CIRCUIT
108: AMPLIFIER

FIG. 6

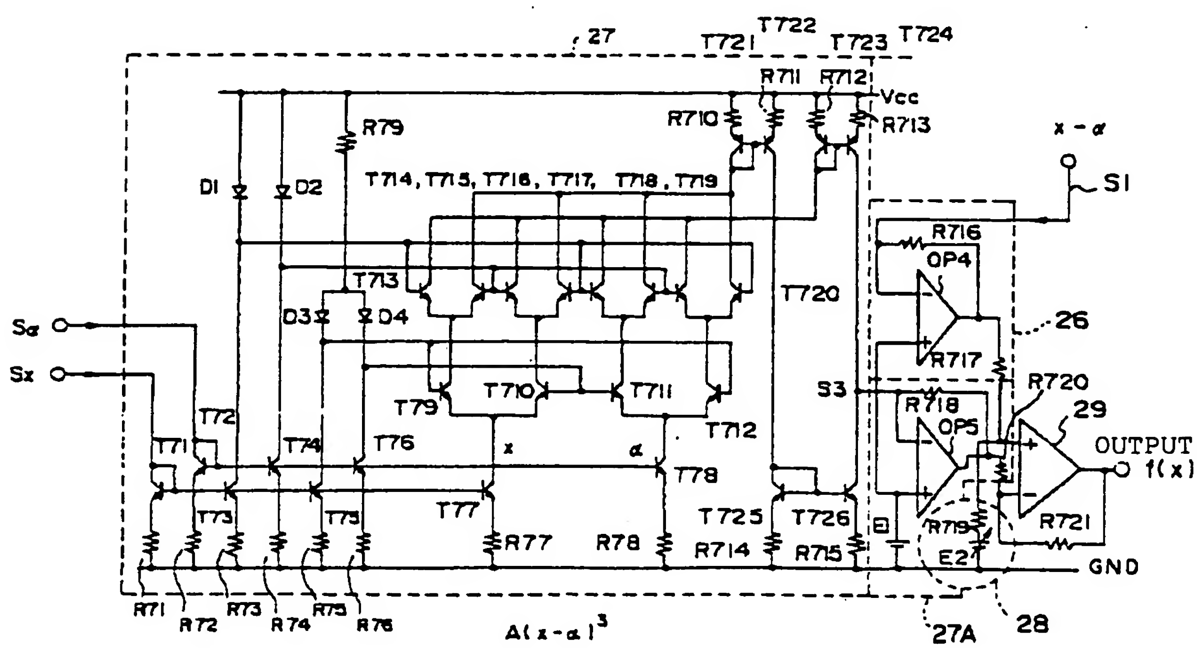
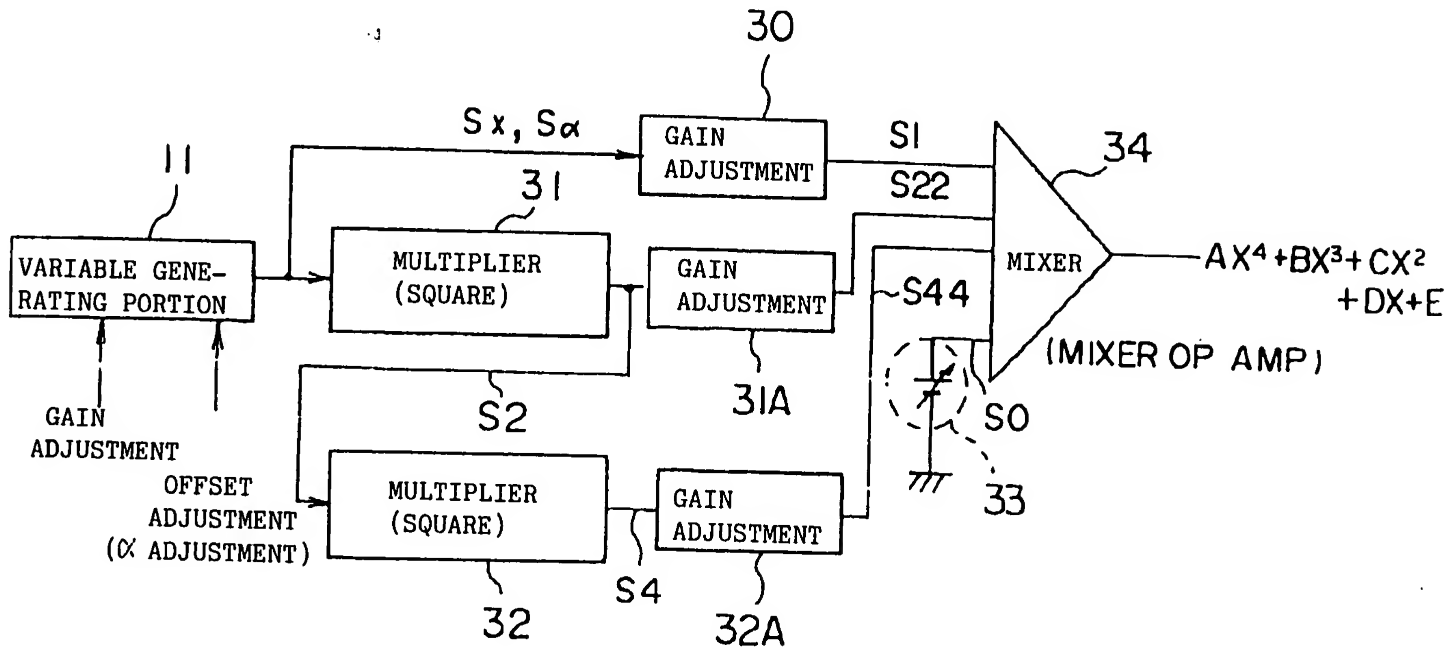


FIG. 7



11
VARIABLE GENE-RATING PORTION
GAIN ADJUSTMENT
OFFSET ADJUSTMENT (α ADJUSTMENT)
Sx, Sα
30
GAIN ADJUSTMENT
31
MULTIPLIER (SQUARE)
GAIN ADJUSTMENT
31A
S2
MULTIPLIER (SQUARE)
32
S4
GAIN ADJUSTMENT
32A
S1
S22
S44
34
MIXER
(MIXER OP AMP)
S0
33
AX4+BX3+CX2 +DX+E

FIG. 8

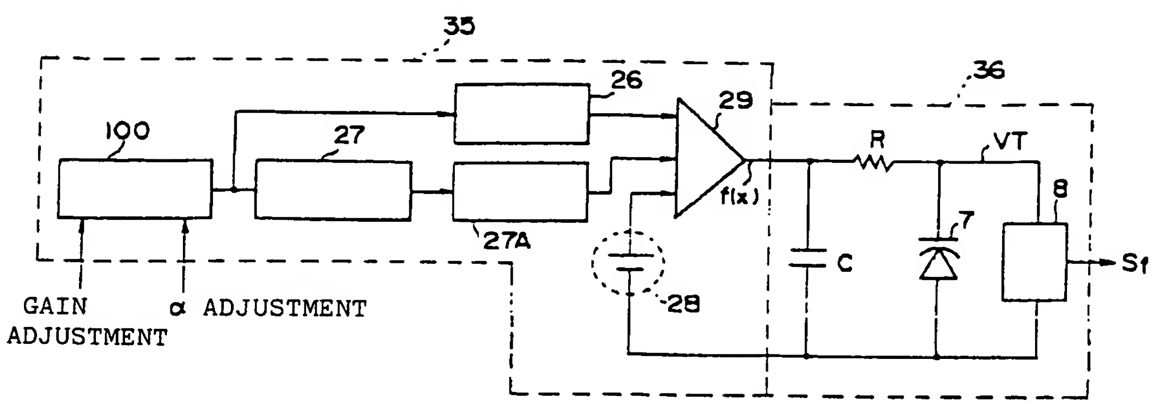
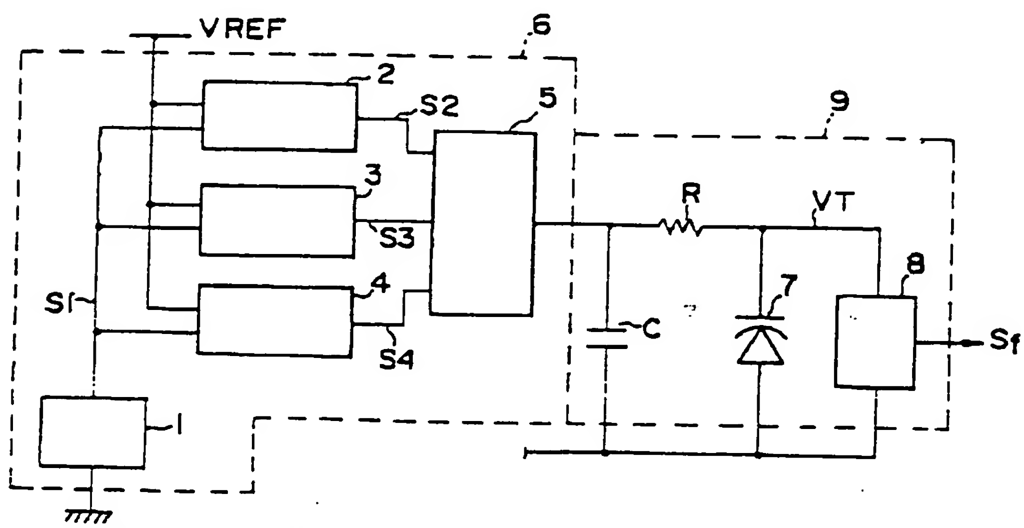


FIG. 9



1: TEMPERATURE SENSOR
2: LOW TEMP. RANGE CORRECTION CIRCUIT
3: MED. TEMP. RANGE CORRECTION CIRCUIT
4: HIGH TEMP. RANGE CORRECTION CIRCUIT
5: I – V CONVERSION CIRCUIT
6: TEMPERATURE COMPENSATION CIRCUIT
7: VARIABLE CAPACITANCE DIODE
8: CRYSTAL RESONATOR
9: CRYSTAL OSCILLATION CIRCUIT

FIG. 10

(a)